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Implementation of Energy-Efficient Protocol for Wireless Sensor Networks on TelosB Mote

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Abstract: Wireless Sensor Networks (WSNs) are formed by hundreds of sensor nodes that are distributed autonomously within the sensing area. It also incorporates with a gateway that provides wireless connection to communicate among nodes and pass data to one and another. There are various applications using WSNs such as wildlife monitoring, environmental monitoring and smart space. The limitation of WSNs is that they are only dependable on power battery to ensure their lifetime as a sensing device. Thus, in order to prolong the network lifetime, various research has been done including the development of energy efficient routing protocols. One of the earliest techniques is Low Energy Adaptive Clustering Hierarchy (LEACH). LEACH protocol uses randomization to select cluster head in order to have an evenly distributed energy among nodes. This work provides an in depth knowledge of LEACH protocol and how it is implemented on TinyOS using a TelosB mote. By implementing a conventional protocol which is Direct Transmission (DT) along with LEACH protocol in nodes, a significant impact on energy dissipation of protocols can be examined. In the findings, LEACH protocol energy usage in transmitting data can be evenly minimized thus lifetime of nodes can be longer. The result shows LEACH saves up to 30% of energy saving than using DT protocol.

Keywords: clustering; energy efficient; wireless sensor networks; telosB.

1. INTRODUCTION

Wireless Sensor Networks (WSNs) are emerging and expanding towards many innovative applications and has been used in various fields of interest, including industrial and research perspectives. The network consists of distributed nodes that are autonomous and sometimes left unattended which can be utilized to monitor physical changes or environmental condition. Sensor nodes of WSNs can cooperatively send their data over a network to the main location or base station. One of the advantages of using WSN is that they can offer a live data feed possibility to the network.

There are also issues that affect the design and performance of WSNs such as hardware and operating software, wireless communication radio, Medium Access Scheme, security and many more. One of the main issues in WSNs is the energy management. Usually in WSN, nodes can be used as an end node or also called base station. Since data collected by each node need to be transferred to the end node wirelessly, a large amount of energy is needed. Nevertheless, the energy in WSNs is very restricted. They are dependable to only battery sources to ensure their lifespan as a sensing device. Traditionally, nodes will turn off their radio power in parliamentary procedure to minimize their power used. Most of sensor nodes are battery operated and the lifetime does not live long. They require to be modified regularly by humans.

Over the past few years, there are many existing routing protocols in WSNs such as Direct Transmission (DT) protocol, Minimum Transmission Energy (MTE) and static clustering. One of the simple protocols that have been used in designing WSN is sleep wake protocol. Sleep wake protocol is an alternative way to conserve energy in WSN [1]. It is performed by putting the nodes into active and sleep mode alternately among sensors. It is also managed to maintain data quality received at base station and also prolong the lifespan of a node compared to the DT protocol.

This paper builds on the application-specific protocol architecture for WSNs introduced in [2] by giving a detailed description and analysis of low-energy adaptive clustering hierarchy (LEACH), thus implemented in TelosB mote using TinyOS. LEACH employs the following techniques to achieve the design goals stated: 1) randomized, adaptive, self-configuring cluster formation; 2) localized control for data transfers; 3) low-energy media access control (MAC); and 4) application-specific data processing, such as data aggregation or compression [2].

After LEACH has been developed, there has been variation in improving LEACH performance as an energy efficient protocol. Some of the variations include LEACH-C, MultiHop LEACH and LEACH-M. LEACH-C is a Centralized Low Energy Adaptive Clustering Hierarchy [3] which involves centralized clustering algorithm. LEACH-C organizes nodes into clusters where each cluster has their own cluster head. This protocol is divided into two phases which is set up phase and steady phase. What differs from LEACH is that the selection of cluster head is done by high energy base station [4]. When sensor nodes need to cover a larger network, LEACH protocol becomes inefficient because of the energy dissipation is unaffordable. Larger network areas will result in high energy transmission in delivering data to base station. To address this problem, Multi Hop LEACH is introduced [5]. Multi Hop LEACH performs clustering in set up phase as in LEACH. In steady phase, Multi Hop LEACH collects all data send by member nodes in its cluster and transmits data directly through intermediate cluster heads which have the highest signal and closest to the base station.

LEACH has been adopted in this paper. By implementing LEACH as a routing protocol, a cluster and a cluster-head will be forged based on the received signal intensity level. Energy in data transmission can be minimized because data transmission to the base station only served by the cluster head rather than all the nodes affected in the cluster network. Therefore, it is crucial for clients to manage their own energy so that the nodes are reliable to transmit data over the base station. The main objective of this paper is to implement and develop the LEACH protocol on the TelosB motes as an energy efficient protocol in WSN in order to prolong the network lifetime and increase the data delivery at the base station. TelosB mote was first developed by University of California, Berkeley in 2005 [6]. This paper contributes to both the research and the industrial community in the area of WSNs.

2. ENERGY EFFICIENT PROTOCOL ARCHITECTURE

The LEACH architecture considers four main criterion in designing the proposed protocol using the TelosB mote such as:

i. Types of sensor nodes
ii. Number of nodes in a network
iii. Area of a network
iv. Network topology

LEACH protocol is implemented in four TelosB motes. Three out of four nodes are selected as nodes and only one node is applied as the base station. Since an energy efficient protocol of LEACH is implemented, the network design is quite different from DT protocol method. All four nodes are created to become a network among them. TinyOS with the programming language of NesC is applied in this work.

The distance between each of the sensor nodes will be set right after the nodes arrangement is fulfilled. The distance of each of the node is crucial as this will indicate the allowable transmission range for nodes. This plays an important role for nodes as it can only communicate with each other in a certain range set by their own nominal range. Every sensor nodes need to send the data to the destination in an energy efficient manner. Moreover, Packet Reception Rate (PRR) of sensor nodes needs to be considered in the overall architecture [7]. In Figure 1, the PRR is acceptable if the distance of nodes to the destination is within 10 meters. When PRR is high, it is assumed no packet is loss during the transmission. In this work, the distance of nodes is set between 7 meters to 10 meters in order for the packet to arrive at the destination without any loss of packet.

Two transmission protocols have been adopted and analyzed in this work, which are LEACH and DT protocol, as benchmarking purposes. LEACH was first developed by Wendi B. Heinzelman in 2002. LEACH is an application specific protocol architecture for WSN [2]. It is a basis algorithm in developing new architecture protocol. LEACH is an adaptive and self-organizing protocol that minimizes the energy consumption of WSNs.

The protocol is based on the randomization rotation of the aggregation so that the energy dissipation is shared among all participating sensor nodes. Total nodes will be divided into small groups or small clusters based on the minimum transmission power to the selected cluster heads. A cluster head will be selected randomly among the nodes and their role as a leader of a cluster will be rotated [2]. A cluster head is selected when random nodes select a number between 1 and 0, and based on certain probability as in [2], the nodes become the cluster head for that current round. Cluster heads' tasks are to compress the data and send the aggregated data to the base station. LEACH process can be divided into rounds and each round is divided into two types of phase which is setup phase and steady state phase.

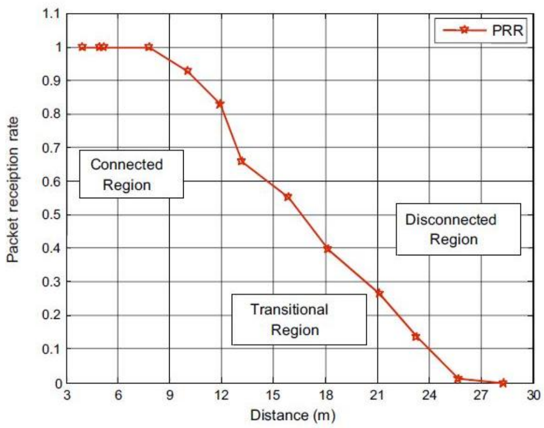

Figure 1. PRR vs. Distance [7]

Cluster head formation takes place in the setup phase. During this phase; the advertisement phase and cluster set up phase occur. Advertisement phase is when a node has been selected to be a cluster head for that particular round. A cluster head node will send an advertisement packet to inform that the node becomes cluster head to the neighboring nodes and other member nodes will respond to the packet and request to join cluster head's cluster. The cluster head creates Time Division Multiple Access (TDMA) schedule for each node and transmits TDMA table to the member nodes. When cluster head is transmitting data to the base station, it is called a steady state phase. The duration of the steady state phase is longer than the setup phase. It is to minimize the overhead occurred.

The flow of the process started with the development of protocol and testing protocol inside TelosB motes. After that, the energy-efficient protocol is implemented on TelosB motes. The TelosB motes which act as sensor nodes are arranged in a grid within 7 to 10 meters away from each other in order to ensure that all packets sent are received by the base station. For both energy efficient LEACH and DT protocols, all of the nodes read voltage values and deliver data every 15 seconds for 12 hours. All received data are collected at the base station, and observation is made. Each of the sensor node sends 5 bytes of packet data which include:

i. Node ID
ii. Internal voltage of sensor node
iii. Data number

Node IDs is the identification set for each sensor node. It is to identify and to ensure which nodes send data to the base station. It also acts as a source address for base station after receiving data from the nodes. Data number acts like a handler data identification for packet data and what type of data is being sent to base station. Every lost packet can also be determined by the data number. Node voltages are supplied by AA batteries and it will indicate how much voltage used for each transmission. The internal voltage sensor uses the microcontroller 12-bit Analog to Digital Converter (ADC) in which the data sent to the base station is written in hexadecimal value. Each of the value is then converted using a program that are created in TinyOS. To convert the raw data to the corresponding voltage value, the equation used for conversion is as below. The value for V_{ref} provided by datasheet is 1.5 V [8,9].

$$\text{Voltage } (V) = (\text{raw value in decimal}) / 4096 * V_{ref} \qquad (1)$$

In the beginning of experiments, both DT and LEACH protocol are implemented in the same network topology where the distance among nodes, the initial voltage value and the number of nodes are set as in Table 1 below. The value of current used can be referred to the TelosB datasheet [8].

Table 1. Design Parameters for LEACH and DT protocol

Parameters	Values
Number of nodes	3 TelosB node
Initial voltage for all nodes	1.5 V
Distance among nodes	7 m – 10 m
Current	1.8 mA

In the development of LEACH protocol by using TinyOS, one node is set as the cluster head and one node acts as the base station that is connected to a computer. The remaining nodes serve as the member nodes. The execution of the process is set to start in 3 ms. After 3 ms, the cluster head broadcasts an announcement packet to the member nodes and the member nodes acknowledge the packet. The cluster head then sends the transmission schedule packet to all member nodes upon receiving the acknowledgement. The timing for all member nodes to send their data to the cluster head is within 12 ms. At 13 ms, the cluster head begins to send all data collected to the base station. After cluster head sends all the data over to the base station, a monitoring of node voltage is done by cluster head. It will then compare each node voltage and if a node has the highest value of voltage, it will be selected as a new cluster head and the process continues until all nodes are running out of energy.

3. RESULTS AND ANALYSIS

3.1 Simulation Result

In this work, a simulation has been done using MATLAB to investigate the performance of the LEACH protocol and DT protocol in a 100 nodes network scenario. An analysis of network lifetime of both protocols are plotted using MATLAB. Figure 2 shows a comparison of the simulated DT protocol and LEACH protocol.

In the beginning of the simulation, there are 100 nodes in the network for both protocols. From Figure 2, it is proven that LEACH has more than double system lifetime compared to DT. LEACH takes a longer time or called round for a node to become a dead node. A node is declared as dead when it has used all the energy or in other words, the energy level is zero. By using a DT protocol, number of alive nodes decreases dramatically at round 150 and last node dies at round 250. Whereas for LEACH, the first node dies only after round 400. Additionally, the number of alive nodes decreases slowly starting at round 400 and reaches its lowest point of alive node at round 900. The analysis has verified that LEACH takes approximately 4 times longer for the first node to die and approximately 8 times longer for the last node to die, as compared to DT protocol.

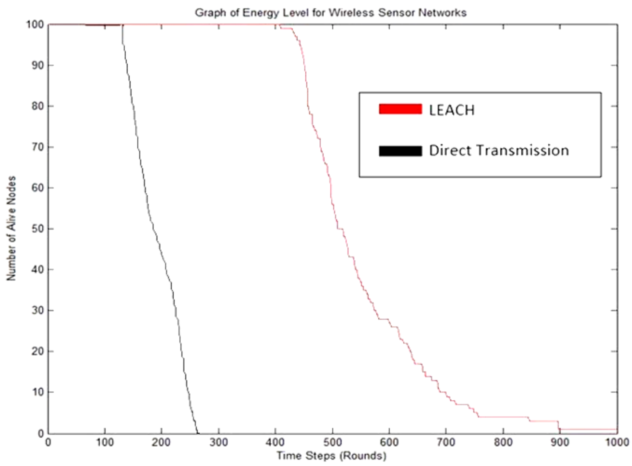

Figure 2. Number of nodes alive versus rounds for different protocols

3.2 Experimental Result

For DT protocol, all nodes are active and send data directly to the base station. All of the nodes in DT protocol consumed higher energy in order to send data to the base station, as compared to LEACH. This is because, all nodes in DT has to send the data directly to the base station. LEACH minimizes the energy consumed by nodes by having only CH to send the data over to the base station. LEACH also performed an evenly distribution of voltage among nodes. Table 3 shows the remaining voltage for both transmission protocols in twelve hours. As illustrated in Figure 3 and 4, red line represents LEACH protocol while blue line represents DT protocol. Overall, it can be seen that in twelve consecutive hours, the remaining voltage for LEACH is higher than DT Protocol.

Table 3. Remaining Voltage of DT and LEACH Protocol

Time (Hour)	Voltage (Volt)	
	Direct Transmission	LEACH
0	1.4995	1.4996
1	1.4252	1.4996
2	1.3759	1.4970
3	1.3385	1.4725
4	1.3227	1.4260
5	1.3092	1.3978
6	1.2579	1.3564
7	1.2579	1.3564
8	1.2117	1.2785
9	1.1667	1.2698
10	1.1473	1.2465
11	1.1467	1.2089
12	1.1276	1.1980

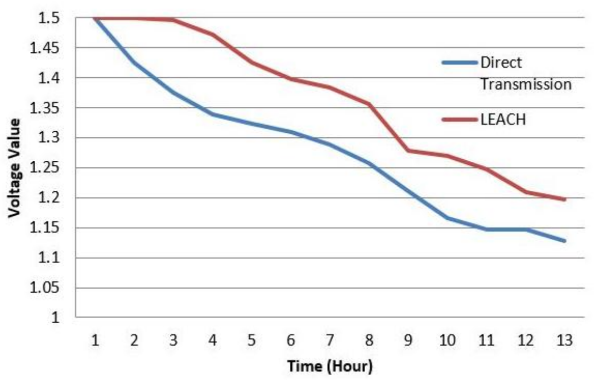

Figure 3. Energy consumption graph of LEACH and Direct Transmission

In the beginning of experiment, both protocol started with the same value of voltage which is 1.5V. In four hours, LEACH protocol still maintains their voltage value at 1.47 V but DT has used up to 1.33 V. In this hour it can be stated that all nodes in DT protocol use a lot of energy to send data directly to the base station. LEACH on the other hand managed to successfully maintain voltage of 9% by having an evenly distributed voltage among nodes. Throughout the process, both protocol voltages are gradually decreasing over time. However, in comparing at sixth hour of experiment, node voltage of DT has reached to 1.25 V but LEACH only at 1.35 V which is higher that DT. Throughout the time, it is demonstrated that the node voltages of DT protocol decreased faster than LEACH. After 12 hours of experiment, the node voltage for LEACH is 26% better than DT protocol. Table 4 shows the energy consumption for LEACH and DT in twelve hours. The energy of nodes is calculated using Equation 2.

$$\text{Energy } (J) = \text{voltage } (V) * I * t \text{ (second)} \qquad (2)$$

From the result, energy consumed by both protocols starts with 0 J. After 1 hour, DT and LEACH start to rise to 0.48 J and 0.0025 J, respectively and end up at 23.48 J and 28.48 J. The total energy consumed by DT protocol is 146.54 J while total energy consumed by LEACH is 102.37 J. It is clearly shown that energy consumption for DT is greater than LEACH protocol.

The network energy graph varies for both protocols because in DT protocol, all nodes use all their energy to send data at the base station at the same time. Nevertheless, in LEACH protocol, only the selected CH send data to the base station. During this particular hour, other consecutive nodes are put to idle to conserve energy. In DT protocol, all sensor nodes continuously read the voltage data and send it to the base station. The energy consumption for nodes is continuously increased over time. The DT results indicate that the energy is used rapidly compared to LEACH. Furthermore, the energy consumed by the network is four times higher than LEACH in the fourth hour of experiment. By having a network that practices an active transmission mode all the time, it results in an increasing number of energy consumed by nodes.

In LEACH protocol, the energy consumption starts to increase at the third hour of experiment and continuously increased over time. This is due to the clustering component in the network. The CH minimizes the overall network energy by collecting its neighboring nodes data and transmits data to the base station. Nevertheless, during the implementation of LEACH in a real test-bed, a little modification has been made to select the CH after the first round. In LEACH, the network experiences even balance energy consumption as at each round new CH is elected based on the probability. However in our work, the CH monitors each node voltage level. By monitoring each node level, current CH intelligently elects a new CH based on the highest voltage level. For instance, at this round, node 2 is the current CH with the voltage value of 1.33 V, while Node 1 has 1.32 V and Node 3 has 1.34 V voltage values. Node 2 selects Node 3 to become the new CH for that particular round based on the voltage value. The process continues until the end of experiment. Total energy can be saved up to 30% for twelve hours using LEACH protocol as compared to DT protocol. This is due to the CH election by having an evenly distributed voltage among nodes to transmit data to base station.

Table 4. Energy Consumption for DT and LEACH Protocol

Time (Hour)	Energy (Joule)	
	Direct Transmission	LEACH
0	0	0
1	0.4847	0.0025
2	1.6083	0.0388
3	3.1395	0.5346
4	4.5956	1.9180
5	6.1819	3.3112
6	8.1764	4.4867
7	10.9816	6.5136
8	14.9454	11.4825
9	19.4380	13.4252
10	22.8549	16.4268
11	25.1832	20.7496
12	28.9578	23.4835
TOTAL	146.5477	102.3736

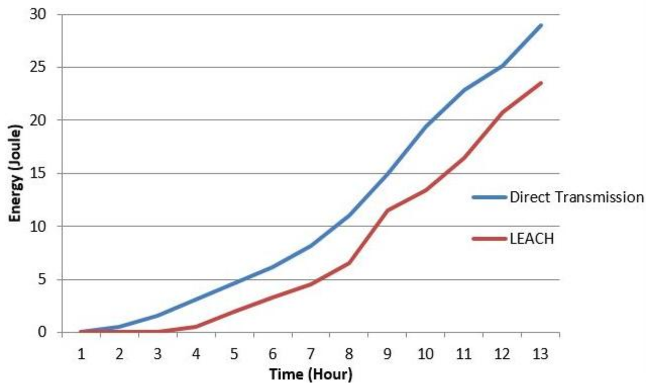

Figure 4. Comparison of Energy in LEACH and DT Protocol

4. CONCLUSION

This paper focused on an implementation of an energy-efficient protocol for WSNs on TelosB mote. Sensing and monitoring application for WSN need to have a long network lifetime. By applying an energy efficient protocol in transmission mode it can help to overcome energy limitation for WSN. LEACH is one of the energy efficient protocols developed for WSN. From the simulation and experimental analysis by using TelosB mote, it is successfully proven that LEACH managed to save up to 30% of energy consumption of nodes compared to DT protocol. LEACH performs a clustering hierarchy by electing a CH. CH operates as a task handler to send all collected data from neighboring nodes to the base station. CH also performs a monitoring task in order to select a new CH based on the highest node voltage. By implementing LEACH as a transmission protocol in TelosB mote, network lifetime of a network can be increased up to 30%.

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REFERENCES

[1] Zhao, F, Xu, Y, & Li, R 2012, ‘Improved LEACH Routing Communication Protocol for a Wireless Sensor Network’, *International Journal of Distributed Sensor Networks,* vol. 2012.

[2] W. Heinzelman, A. Chandrakasan, and H. Balakrishnan, “Energy-ef- ficient routing protocols for wireless microsensor networks,” in *Proc. 33rd Hawaii Int. Conf. System Sciences (HICSS),* Maui, HI, Jan. 2000

[3] W. Heinzelman, Chandrakasan, A. P., and Balakrishnan, H. (2002), “An application-specific protocol architecture for wireless microsensor networks,” Wireless Communications, IEEE Transactions on, 1(4) pp. 660-670.

[4] Omari, M & Fateh WH 2015, ‘Enhancing Multihop Routing Protocols in Wireless Sensor Networks using LEACH-1R’, in 2015 2nd World Symposium on Web Applications and Networking (WSWAN), pp. 1-6, IEEE, Sousse.

[5] Rajashree.V.Biradar, Dr.S.R. Sawant, Dr. R. R. Mudholkar , Dr. V.C .Patil ”Multihop Routing In Self-Organizing Wireless Sensor Networks” IJCSI International Journal of Computer Science Issues, Vol. 8, Issue 1, January 2011.

[6] Polaste, J, Szewczyk, R & Culler, R 2005, ‘Telos: Enabling Ultra-Low Power Wireless Research’, *Proceedings of the 4th international symposium on information processing in sensor networks,* no. 48, IEEE, Piscataway NJ.

[7] 7P. Levis, S. Madden, J. Polastre, R. Szewczyk, K. Whitehouse, A. Woo, D. Gay, J. Hill, M. Welsh, E. Brewer, and D. Culler “TinyOS: An operating system for wireless sensor networks,” in Ambient Intelligence. Springer-Verlag (2005).

[8] *TinyOS Tutorials* n.d., Available from: < http://tinyos.stanford.edu/tinyos-wiki/index.php/TinyOS_Tutorials>. [24 May 2016]

[9] TelosB Datasheet [Online], Available: http://www.xbow.com/Products/Product_pdf_files/Wireless_pdf/TelosB_Datasheet.pdf